



Open Source Solutions for Cloud Computing

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The availability of many open source systems offers affordable opportunities for organizations to build and adopt various types of cloud computing environments.

Cloud computing—which lets organizations access resources on demand via the Internet, rather than having to provide applications and services on their own—has emerged as a cost-effective and efficient way to deploy IT solutions. However, commercial, proprietary cloud products are often expensive. Open source cloud-computing systems, on the other hand, offer cheaper, vendor-independent alternatives¹⁻³ that provide scalability, customizability, security, interoperability, and easier migration.

Communities of skilled volunteers working together over the Internet collaboratively develop open source, cloud-based infrastructure as a service (IaaS), platform as a service (PaaS), software as a service (SaaS), and hypervisor systems, which continue to evolve and improve. Their features and compatibility with existing infrastructures have increased industry adoption by leading firms and start-ups.

I address these matters in this article, which is an abridged, updated version of a chapter that I co-wrote on this topic published in *Encyclopedia of Cloud Computing*.⁴

OPEN SOURCE IAAS

IaaS provides customers with raw computing infrastructure, including storage, processing, and networking



TABLE 1. Comparison of open source infrastructure-as-a-service (IaaS) offerings.

Criteria	Eucalyptus	OpenStack	CloudStack
Ease of deployment and management	Amazon Web Services (AWS)–compatible API; web-based management console	Automated deployment and management using the open source Compass system	Web-based management of server provisioning, hosts, storage, and other elements
Provisioning and orchestration	Supported by cloud controller, cluster controller, and node controller	Uses Heat Orchestration Template, via Representational State Transfer (REST) APIs to launch multiple composite-cloud applications	Supported by the CloudStack orchestration engine
Monitoring and alerts	Supports tools like Ganglia and Nagios Supported by Eucalyptus Stats and Amazon's Cloudwatch	Supports tools like Nagios and Ganglia Supported by OpenStack Telemetry	Supports tools like Zenoss and Nagios Supports notifications via email and management server
Interoperability	Supports AWS API, EC2 (Elastic Compute Cloud), and S3 (Simple Storage Service)	Supports RefStack and Citrix Systems' NetScaler SD-WAN	Supports NetScaler SD-WAN
Networking modes and services	Edge, managed (virtual LAN/non-VLAN), virtual-private-cloud networking modes	API-driven networking service VLAN, flat, generic routing encapsulation, and virtual extensible LAN networking modes	Basic (layer 3 filtering) zone and advanced zone
Storage	Allocation and deallocation of memory on demand by the storage controller	Supported by ephemeral file system, block storage cinder, Object Storage (Swift), and shared file system	Primary storage: disk volumes for guest virtual machines associated with cluster Secondary storage: Network File System-based storage
Security	Security groups (networking rules applied to all associated instances [layer 2 isolation]), identity access control	Components for identity provisioning, password management, and authentication	Web sessions, Data Encryption Standard–encrypted tokens, security groups
Support	Supported by knowledge base, documentation, web-based issue tracking, community forum, reference architectures, and expert support from Hewlett Packard Enterprise	Supported by Internet relay chat (IRC), documentation and community forum, and vendor support	Supported by documentation, community support, and IRC channel

resources. There are several popular open source IaaS systems (see Table 1).

For example, Hewlett-Packard's HPE Helion Eucalyptus (www.eucalyptus.com)—elastic utility computing architecture for linking programs to useful systems—is a scalable IaaS framework that uses the Amazon Web Services (AWS) API to enable interoperability and cloud creation. It supports KVM (kernel-based virtual machine), Xen, and VMware virtualization; runs on

major Windows and Linux distributions; and integrates with Amazon's S3 (Simple Storage Service) and EC2 (Elastic Compute Cloud) public clouds.

OpenStack (www.openstack.org) offers a modular architecture that provides a component-based way to build clouds. It was developed by cloud-computing vendor Rackspace Inc. and NASA, and is supported by companies such as Hewlett-Packard, IBM, and Intel.

Apache CloudStack (cloudstack.apache.org) supports KVM, VMware's vSphere, and Xen virtualization, and offers a management server with a web dashboard.

OPEN SOURCE PAAS

PaaS offers development and middleware systems for designing and testing software. There are several noteworthy open source PaaS platforms (see Table 2).

TABLE 2. Comparison of open source platform-as-a-service (PaaS) solutions.

Criteria	Cloud Foundry	Cloudify	OpenShift
Ease of deployment	Provides services for easy development Supports command-line interface (CLI) pushes and many languages	Supports dynamic provisioning and automatic resource scalability	Provides automatic deployment through Git pushes or the Red Hat Cloud (RHC) CLI tool
Security	Provides account authentication as an identity-management service	Supports role- and resource-based authorization security	Uses firewalls, intrusion-detection systems, port monitoring, RPM (Red Hat's RPM package manager) verification, and encrypted communication
Features	Supports multiple languages and frameworks with flexible configurations	Provides a simple orchestration tool to configure and manage cloud resources and to better support integration with external tools	Supports multiple languages and databases
Service metering	Offers REST (Representational State Transfer)-based metering and aggregation services via cf-abacus, Cloud Foundry's usage-metering engine	Supports third-party metering service for accounting of pay-per-use resources	Provides microservice metering, which measures units consumed at the container level
Resilience	Provides virtual-machine resurrection and cross availability-zone redundancy	Supports automatic resource control	Allows failovers and loose-service coupling for resilience Allows both vertical (more resources) and horizontal (more instances) scaling via the open source HAProxy TCP/HTTP load balancer

VMware, Dell EMC, and General Electric developed Cloud Foundry (www.cloudfoundry.org) as a self-service application-execution engine, automated deployment engine, and lifecycle manager, integrated with various development tools. It uses a scriptable command-line interface.

Cloudify (getcloudify.org) is a TOSCA (topology and orchestration specification for cloud applications)-based cloud orchestration framework that models applications and services, and automates their entire lifecycles.

OpenShift (www.openshift.com), which open source software vendor Red Hat developed, leverages both Kubernetes, Google's open source container cluster manager, and Docker, an open source system that automates the deployment of Linux applications within containers. OpenShift adds DevOps tools to improve deployed applications' development and maintenance.

OPEN SOURCE SAAS

SaaS offers software hosted on a provider's infrastructure. Open source SaaS cloud systems allow rapid customization and extension of the provided software. There are several important open source SaaS cloud offerings (see Table 3).

Acquia (www.acquia.com) enables hosting of the Drupal content-management system on the Amazon EC2 cloud service to create a digital foundation for delivering web content.

SuiteCRM (suitecrm.com) is a customer relationship management (CRM) application.

Openbravo (openbravo.com) is enterprise resource planning (ERP) software.

OPEN SOURCE HYPERVISORS

Hypervisors are the foundation of cloud computing, providing a way to create, run, manage, and delete VMs on the fly without changing the hardware

environment. They also enable resource sharing. There are several leading open source hypervisors (see Table 4).

KVM (www.linux-kvm.org) is a Linux kernel module that permits VM hosting. It is a virtualization infrastructure for the Linux kernel that turns it into a hypervisor.

OpenVZ (openvz.org) allows OS-level virtualization by creating multiple secure, isolated Linux containers on a single server. This enables better server utilization and avoids application conflicts.

Xen (www.xenproject.org) uses a microkernel to provide services that run a VM. It lets multiple OSs execute on the same hardware simultaneously and enables VM migration over a LAN.

The availability of many open source cloud offerings lets organizations adopt a holistic cloud ecosystem in which

TABLE 3. Comparison of open source software-as-a-service (SaaS) offerings.

Criteria	Acquia	SuiteCRM	Openbravo
Features and applicability	A content-management system that lets users add modules and perform custom coding as needed Provides a content-delivery network	A fully customizable customer relationship management system that lets users extend its functionality as needed	A web-based enterprise resource-planning system that automates most common business processes
Security	Supports physical security, customer segregation, system-access controls, OS and LAMP-stack security-patch management, antivirus upload scanning, file-system encryption, SSL, HTTPS, data and physical media destruction, and logging	Supports role-based security models with the configuration of network security such as SSL and HTTPS Provides OS security by including access control, file-system encryption, and so on	Supports SSL and HTTPS
Scalability	Manages sudden traffic spikes	Uses the Network File System	Uses model-view-controller programming to enable scalability
Support	Includes community forum, documentation, and Internet relay chat	Includes community forum and documentation	Includes community forum and documentation

TABLE 4. Comparison of open source hypervisors.

Criteria	KVM	OpenVZ	Xen
Supported hosts	Supports x86 and x86-64 Ported to ARM, PowerPC, and IA-64	Supports x86 and x86-64	Available for ARM, IA-32, x86, and x86-64
Features	Provides emulation via QEMU, an open source hypervisor Provides paravirtualization	Provides virtualization, checkpointing, isolation, and resource management	Provides virtual machine migration over a LAN, hardware-assisted virtualization, and paravirtualization
Supported guest OS	Runs UNIX-like distributions, Windows, OS X, Android, and Solaris	Supports only Linux distributions	Runs most UNIX-like distributions and runs Windows with virtualization support
Support	Includes forums and online tracking	Supported by online forums, as well as wiki and issue/source tracking via a Git repository	Includes a knowledge center, online forums, training, and paid Citrix Systems support

organizations can adopt different solutions for different purposes, based on what's best for them. Table 5 lists some of the organizations supporting open source cloud systems.

Open source cloud solutions offer freedom of reuse and promote innovation. Their vendor neutrality and interoperability make migration cost-effective and easy. However, security issues, lack of service support, and the shortage of IT workers skilled

in these systems still limit adoption. Thus, more research is needed in these areas. ■

ACKNOWLEDGMENTS

I would like to thank University of Hyderabad PhD student Deepnarayan Tiwari and Srinivas Komaragiri, a post-graduate student in banking technology at the Institute for Development and Research in Banking Technology, for their useful insights.

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TABLE 5. Organizations supporting open source cloud systems.

Category	Open source cloud system	Organizations
IaaS	Eucalyptus	Hewlett Packard Enterprise
	OpenStack	Best Buy, Bloomberg, Comcast, PayPal Holdings
	CloudStack	China Telecommunications, DataCentrix Holdings, University of Melbourne
PaaS	CloudFoundry	Cisco Systems, Hewlett Packard Enterprise, IBM, SAP
	Cloudify	GigaSpaces Technologies, VMware
	OpenShift	6Fusion, Accenture, Vizuri
SaaS	Acquia	Australian government, BBC, Warner Music Group
	SuiteCRM	NHS England
	Openbravo	Decathlon, Home's Up
Hypervisor	KVM	IBM, Linux
	OpenVZ	Virtuozzo
	Xen	Cavium, Intel

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